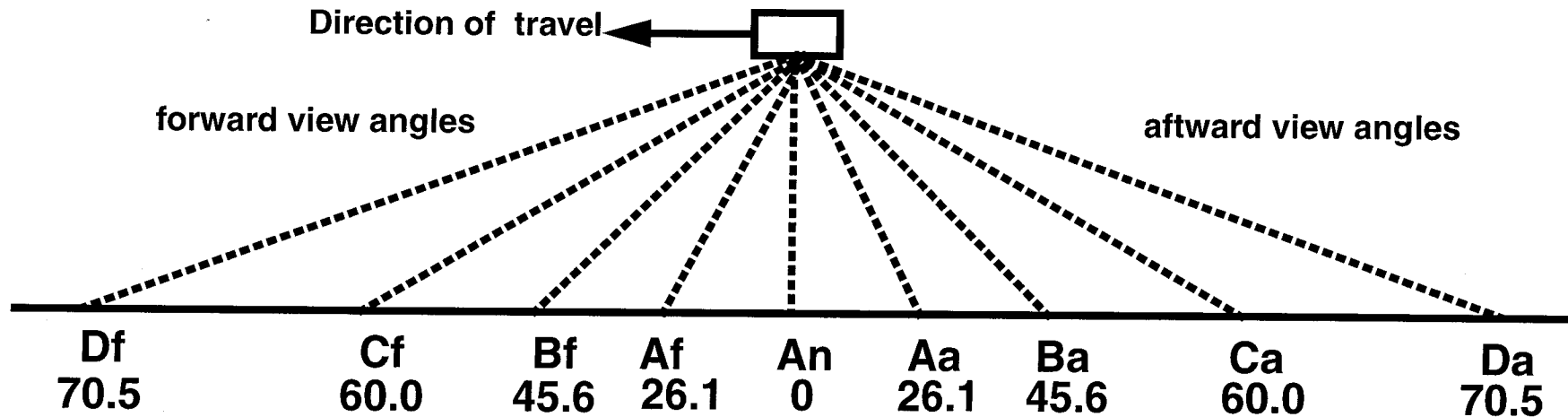**MISR**

Multi-angle
Imaging
Spectro-
Radiometer

Use of HDF and HDF-EOS in MISR Standard Data Products
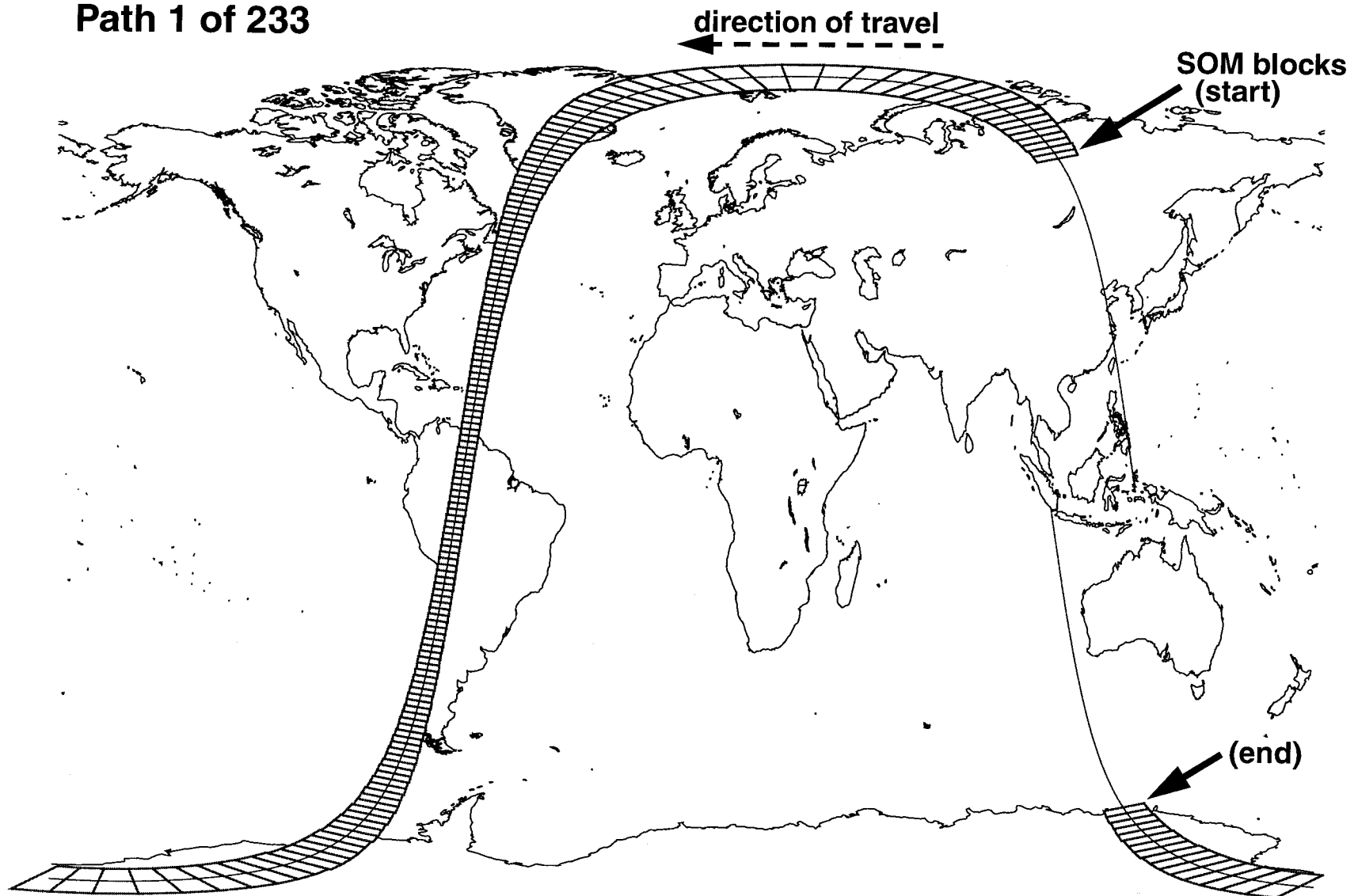
Mike Bull

HDF-EOS Workshop IV

September 20, 2000

- **Background**
  - MISR Instrument & MISR Orbit
  - MISR Standard Processing

- **MISR Standard Data Products**
  - Reformatted Annotated Product (Level 1A)
  - Radiometric Product (Level 1B1)
  - Georectified Radiance Product (Level 1B2)
  - Top-of-atmosphere / Cloud Product (Level 2TC)
  - Aerosol / Surface Product (Level 2AS)
  - Level 3 Product

- **SOM Map Projection & SOM Blocks**

- **MISR Metadata (use of native HDF structures)**

- **Lessons Learned**

JPL

MISR

Direction of travel ← ☐

forward view angles   aftward view angles

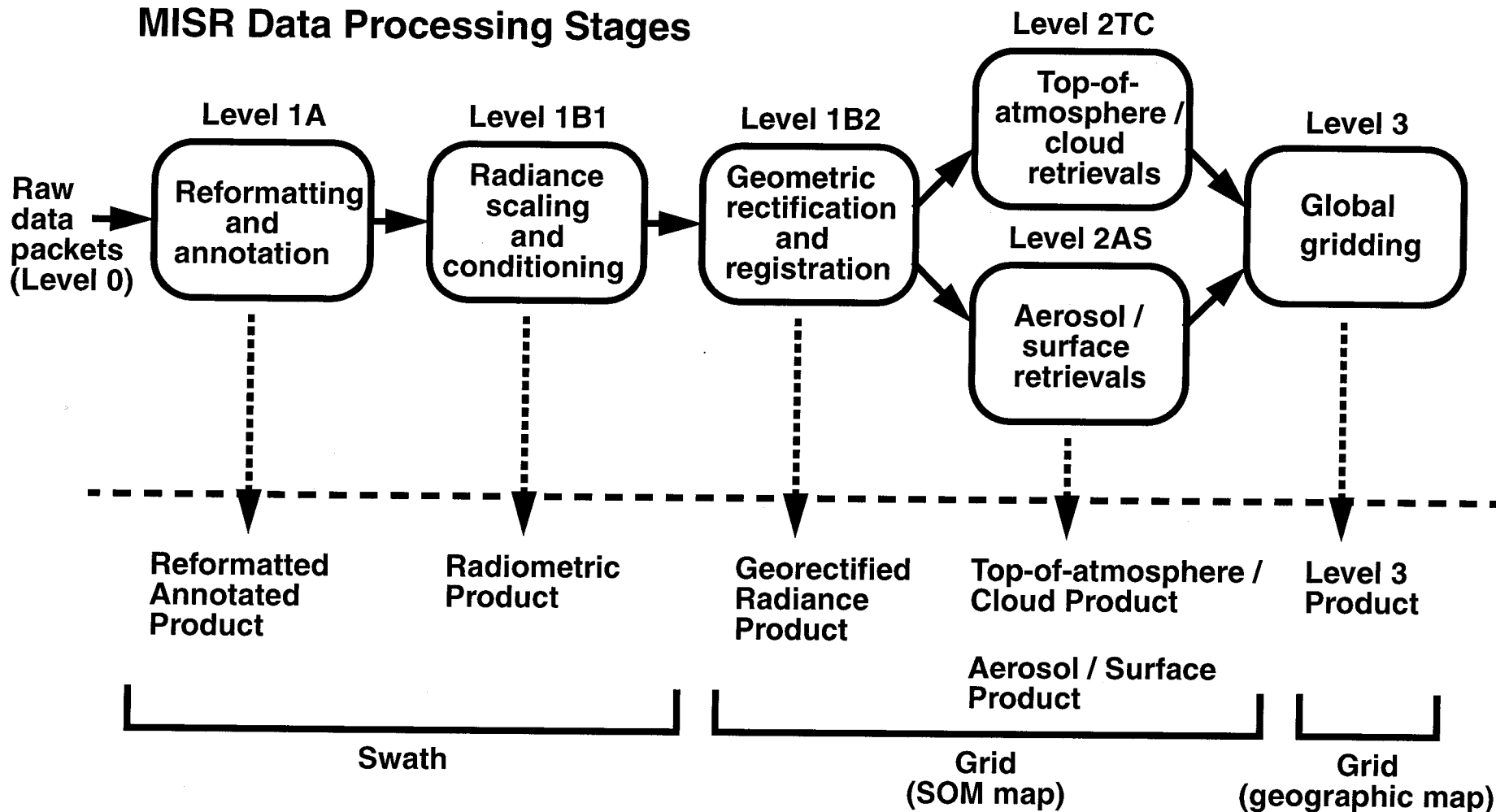| Df	Cf	Bf	Af	An	Aa	Ba	Ca	Da
70.5	60.0	45.6	26.1	0	26.1	45.6	60.0	70.5

- 9 cameras: 4 forward views, 4 aftward views, 1 nadir

- 4 spectral bands in each camera: blue, green, red, infrared

- Each MISR image swath is 360 km wide and approximately 20000 km long.

JPL

direction of travel

SOM blocks (start)

(end)

MISR Data Processing Stages

Raw data packets (Level 0) →

Level 1A
Reformatting and annotation →

Level 1B1
Radiance scaling and conditioning →

Level 1B2
Geometric rectification and registration →

Level 2TC
Top-of-atmosphere / cloud retrievals →

Level 2AS
Aerosol / surface retrievals →

Level 3
Global gridding

Reformatted Annotated Product

Radiometric Product

Georectified Radiance Product

Top-of-atmosphere / Cloud Product

Aerosol / Surface Product

Level 3 Product

Swath

Grid (SOM map)

Grid (geographic map)

MISR Standard Data Products

HDF files corresponding to MISR Standard Data Products

MISR Name	EOSDIS Name	File Type	Description
Level 1A			Reformatted Annotated Product (23 files)
FM_BR	MISBR	hdf	Browse image (8-bit raster, JPEG)
FM_SCI	MIL1A	swath	CCD Science Data (x 9 -- one file per camera)
FM_CAL	MI1AC	swath	CCD Calibration Data (x 9)
FM_MTR	MI1AMOT	swath	Motor data
FM_ENG	MI1AENG1	swath	Engineering Data
FM_NAV	MI1ANAV	swath	Navigation Data
FM_OBC	MI1AOBC	swath	On Board Calibration Data
Level 1B1			Radiometric Product (9 files)
RP	MI1B1	swath	Radiometric Product (x 9)
Level 1B2			Georectified Radiance Product (28 files)
GRP_ELLIPSOID	MI1B2E	grid	Ellipsoid-projected top-of-atmosphere radiance (x 9)
GRP_TERRAIN	MI1B2T	grid	Terrain-projected top-of-atmosphere radiance (x 9)

MISR Standard Data Products

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MISR

HDF files corresponding to MISR Standard Data Products

MISR Name	EOSDIS Name	File Type	Description
GP_GMP	MIB2GEOP	grid	Geometric parameters
GRP_RCCM	MIRCCM	grid	Radiometric Camera-by-camera Cloud Mask (x 9)
Level 2TC			Top-of-Atmosphere / Cloud Product (3 files)
TC_ALBEDO	MIL2TCAL	grid	Albedo Parameters
TC_STEREO	MIL2TCST	grid	Stereo Parameters
TC_CLASSIFIERS	MIL2TCCL	grid	Classifier Parameters
Level 2AS			Aerosol / Surface Product (3 files)
AS_AEROSOL	MIL2ASAE	grid	Aerosol Parameters
AS_LAND	MIL2ASLS	grid	Land Surface Parameters
AS_OCEAN	MIL2ASOS	grid	Ocean Surface Parameters
Level 3			Level 3 Product (32 files proposed)
not yet available		grid	Monthly, seasonal, and annual summaries of Level 2 parameters projected onto global geographic grid.

JPL | Reformatted Annotated Product (L1A) MISR

Summary of files

File	Description
Browse Image	Provides a "thumbnail" image of the nadir view for the entire swath, reduced in size by a factor of 16. Implemented as a single JPEG image encapsulated in an HDF file.
CCD Science	Raw CCD image data reported for each camera, band, and averaging mode. Time tag and statistical summaries reported for each line.
CCD Calibration	Raw CCD calibration data reported for each camera, band, and averaging mode. Time tag and statistical summaries reported for each line.
Motor	Measurements of the instrument's motor current values and temperatures.
Engineering	Measurements of temperatures, voltages and currents of MISR intrument systems. Status of movable calibration panels and latching mechanisms.
Navigation	Spacecraft position, velocity, attitude and attitude rate.
On-board Calibration	Radiometry measurements from PIN and HQE diodes and goniometer mechanism readings. Used to determine brightness and reflective characteristics of a MISR diffuser panel as observed by MISR's cameras.

JPL | **Reformatted Annotated Product (L1A)** | *MISR*

- ## **CCD Science Data**
  - Image resolution depends on averaging mode:

1x1 = 275 meter	1x4 = 275 x 1100 meter
2x2 = 550 meter	4x4 = 1100 meter

  - Create a separate HDF-EOS swath file for each camera.
  - Within each file, for each of 16 combinations of band and averaging mode, create two swaths: one for CCD image data, the other for time tags and statistics.
  - Along-track dimension is image line number (equivalent to time).
  - For CCD image data, cross-track dimension is the CCD pixel number.
  - For time tags and statistics, cross track dimension separates the data values reported for each line. (Similar to a Vdata with one record per line).

- ## **CCD Calibration Data**
  - HDF-EOS structure is the same as described above for the CCD Science Data.

HDF-EOS Structure of CCD Science/Calibration Data

CCD Image Data

	1x1	2x2	1x4	4x4
Blue	swath	swath	swath	swath
Green	swath	swath	swath	swath
Red	swath	swath	swath	swath
Infrared	swath	swath	swath	swath

Time Tags & Statistics

	1x1	2x2	1x4	4x4
Blue	swath	swath	swath	swath
Green	swath	swath	swath	swath
Red	swath	swath	swath	swath
Infrared	swath	swath	swath	swath

- One file for each camera.
- 32 swaths per file.
- Pair of swaths for each combination of band and averaging mode.
- One field per swath.

- **Motor Data**
    - Contains one swath with multiple data fields.
    - Along-track dimension is record number (and corresponds to time).
    - Cross-track dimension separates subfields within each swath data field. (Similar to a Vdata).
    - Along track dimensions for each field are linked by a time dimension (using SWdefdimmap), allowing data to be subsetted by time.

- **Engineering Data**
    - HDF-EOS structure is the same as described above for the Motor Data.

- **Navigation Data**
    - HDF-EOS structure is the same as described above for the Motor Data.

- **On Board Calibration Data**
    - HDF-EOS structure is the same as described above for the Motor Data.

- **Radiometric Product**
  - Image data converted to spectral radiances. Determined from measurements of MISR camera responses to known radiance fields taken during pre-flight and in-flight calibration activities.
  - Data is reported for each camera and band. A data quality indicator is reported for each radiance value. Acquisition time is reported for each image line.
  - Resolution is dependent on camera and band: nominally 275 meter for all bands of the nadir camera, and for the red band of all cameras; 1.1 km resolution for all other cameras and bands.
  - Create a separate HDF-EOS swath file for each camera.
  - Each file contains 4 swaths, corresponding to bands.
  - Along-track dimension is image line number (equivalent to time).
  - Cross-track dimension is CCD pixel number.
  - Each swath has 3 data fields: radiance, data quality, and time table.
  - Radiance and data quality use both along-track and cross-track dimensions. The time table is a one-dimensional field, using only the along-track dimension.
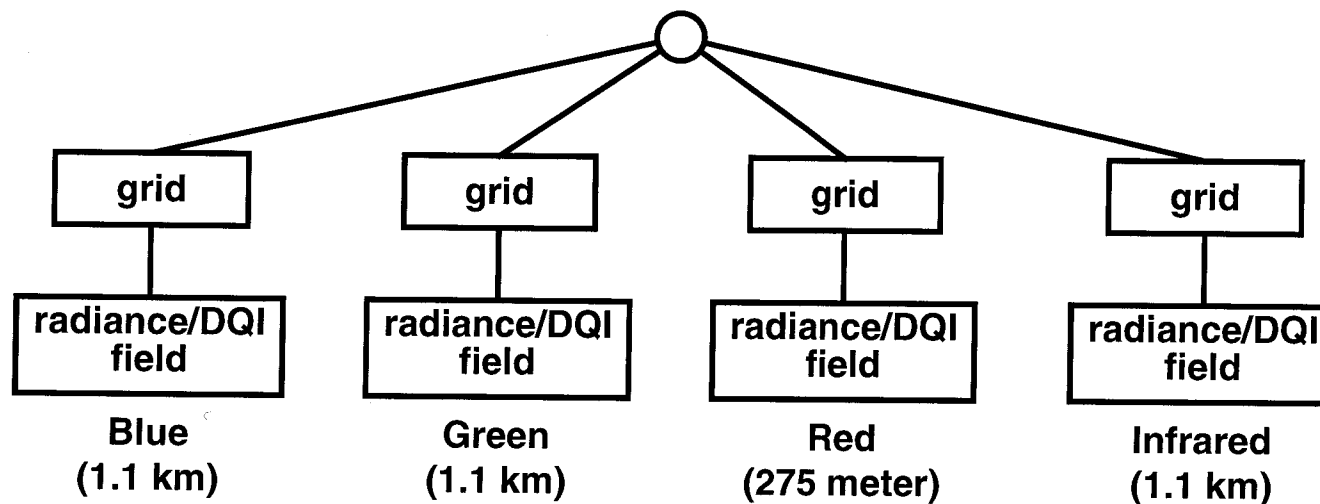
HDF-EOS Structure of Radiometric Product File

swath	swath	swath	swath
radiance field	radiance field	radiance field	radiance field
data quality field	data quality field	data quality field	data quality field
time table field	time table field	time table field	time table field

Blue	Green	Red	Infrared
(1.1 km)	(1.1 km)	(275 meter)	(1.1 km)

- One file for each camera.
- Resolution dependent on band and camera.

JPL | Georectified Radiance Product (L1B2) | *MISR*

Summary of files

File	Description
Ellipsoid-projected radiance	Geolocated radiance data, projected to the Space-Oblique Mercator (SOM) map grid. Geometric corrections are applied to remove errors in spacecraft position and pointing knowledge. The data is resampled to the reference ellipsoid (WGS84).
Terrain-projected radiance	Same as above, except that additional processing is performed over land to correct for errors due to surface topography. The data is then ortho-rectified to the reference ellipsoid.
Geometric Parameters	Sun angle and MISR camera view angles, reported in azimuth and zenith.
Radiometric Camera-by-camera Cloud Mask	Indicates cloudy or clear at each grid location with varying degrees of confidence. Indicates locations potentially glitter contaminated due to sun reflections on water. This is used determine which regions are suitable for Level 2 algorithms that are sensitive to clouds and/or glitter.

- **Ellipsoid-projected top-of-atmosphere radiance**
    - Data is reported for each camera and band. A data quality indicator is reported at each grid location.
    - Resolution is dependent on camera and band: nominally 275 meter for all bands of the nadir camera, and for the red band of all cameras; 1.1 km resolution for all other cameras and bands.
    - Create a separate HDF-EOS grid file for each camera.
    - Each file contains 4 grids, corresponding to bands.
    - XDim and YDim correspond to the SOM X and Y dimensions.
    - Each grid contains 1 field with combined radiance and data quality.

- **Terrain-projected top-of-atmosphere radiance**
    - Not reported over ocean.
    - HDF-EOS structure is the same as for the Ellipsoid-projected data.

HDF-EOS Structure of Ellipsoid/Terrain-projected
Top-of-atmosphere Radiance File

```
                              ◯
              ╱          ╱         ╲          ╲
        ┌─────────┐  ┌─────────┐  ┌─────────┐  ┌─────────┐
        │  grid   │  │  grid   │  │  grid   │  │  grid   │
        └────┬────┘  └────┬────┘  └────┬────┘  └────┬────┘
        ┌────┴────┐  ┌────┴────┐  ┌────┴────┐  ┌────┴────┐
        │radiance/│  │radiance/│  │radiance/│  │radiance/│
        │DQI field│  │DQI field│  │DQI field│  │DQI field│
        └─────────┘  └─────────┘  └─────────┘  └─────────┘
          Blue         Green         Red        Infrared
        (1.1 km)     (1.1 km)    (275 meter)    (1.1 km)
```

- One file for each camera.
- Resolution dependent on band and camera.

JPL | Georectified Radiance Product (L1B2)   *MISR*

- **Geometric parameters**
  - Resolution is 17.6 km.
  - One HDF-EOS grid file contains data for all cameras.
  - Each file contains 1 grid, with 20 fields: 18 fields contains azimuth and zenith angles for each MISR camera, 2 fields contain solar azimuth and zenith.

- **Radiometric Camera-by-camera Cloud Mask**
  - Reported for each camera. A data quality indicator is also reported at each grid location.
  - Resolution of 1.1 km.
  - Create a separate HDF-EOS grid file for each camera.
  - Each file contains 1 grid, with 3 fields: cloud mask, glitter mask, and data quality indicator.

Summary of Files

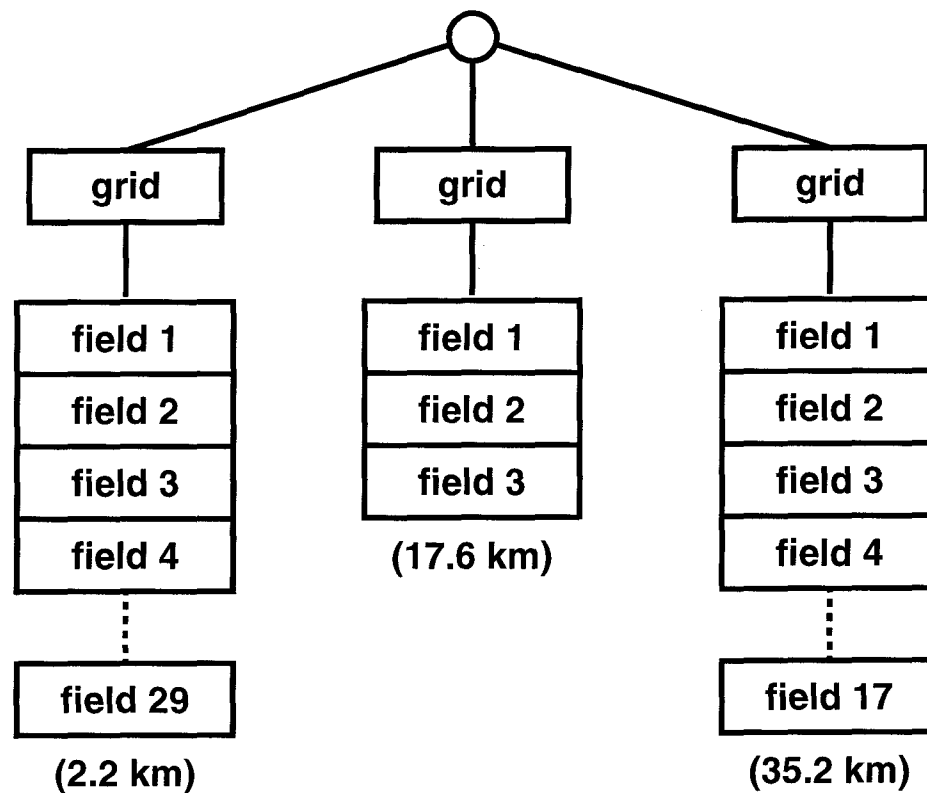| File	Description
Top-of-atmosphere / Cloud Product	
Albedo	Amount of solar radiation absorbed or reflected by clouds (i.e., cloud albedo).
Stereo	Stereoscopically derived cloud mask; cloud hieghts; identification of snow & ice; altitude of primary reflecting layer (e.g., top of clouds or surface); wind speed estimates based on cloud motion.
Classifiers	Angular signature cloud mask; identification of cloud shadows, and shadows caused by surface topography.
Aerosol / Surface Product	
Aerosol	Estimated amount and types of atmospheric particles (aerosols).
Land	Reflectance characteristics of land surfaces and vegetation; amount of solar radiation absorbed or reflected by land surfaces and vegetation (i.e., surface albedo); angular reflectance properties of various vegetation types.
Ocean	Estimate of phytoplankton pigment concentration, based on ocean color.

- **Level 2 Parameter Files**
  - All level 2 parameter files have the same basic structure.
    (see diagram for Albedo Parameters file, next page)
  - Each file contains multiple parameters reported at a variety of resolutions.
  - A separate grid is created for each resolution used.
  - Each grid contains one field for each parameter.
  - Many fields have one or two additional dimensions.

Approximate number of parameters reported in each spatial resolution

File	1.1 km	2.2 km	17.6 km	35.2 km	70.4 km
Albedo		29	3	17	
Stereo	18	2			79
Classifiers	3		22		
Aerosol	2		60		3
Land	19		14		
Ocean	9		2		

HDF-EOS Structure of Albedo Parameters File

```
                              ○
              ┌───────────────┼───────────────┐
        ┌──────────┐    ┌──────────┐    ┌──────────┐
        │   grid   │    │   grid   │    │   grid   │
        └──────────┘    └──────────┘    └──────────┘
             │               │               │
        ┌──────────┐    ┌──────────┐    ┌──────────┐
        │ field 1  │    │ field 1  │    │ field 1  │
        ├──────────┤    ├──────────┤    ├──────────┤
        │ field 2  │    │ field 2  │    │ field 2  │
        ├──────────┤    ├──────────┤    ├──────────┤
        │ field 3  │    │ field 3  │    │ field 3  │
        ├──────────┤    └──────────┘    ├──────────┤
        │ field 4  │     (17.6 km)      │ field 4  │
        └──────────┘                    └──────────┘
             ┆                               ┆
        ┌──────────┐                    ┌──────────┐
        │ field 29 │                    │ field 17 │
        └──────────┘                    └──────────┘
         (2.2 km)                        (35.2 km)
```

• one grid for each resolution
• one field for each parameter

- **Level 3 Product**
    - Monthly, seasonal and annual summaries of Level 2 parameters mapped onto a global geographic projection.
    - Selection of parameters to be reported is not yet finalized.
    - All files use HDF-EOS grid format.
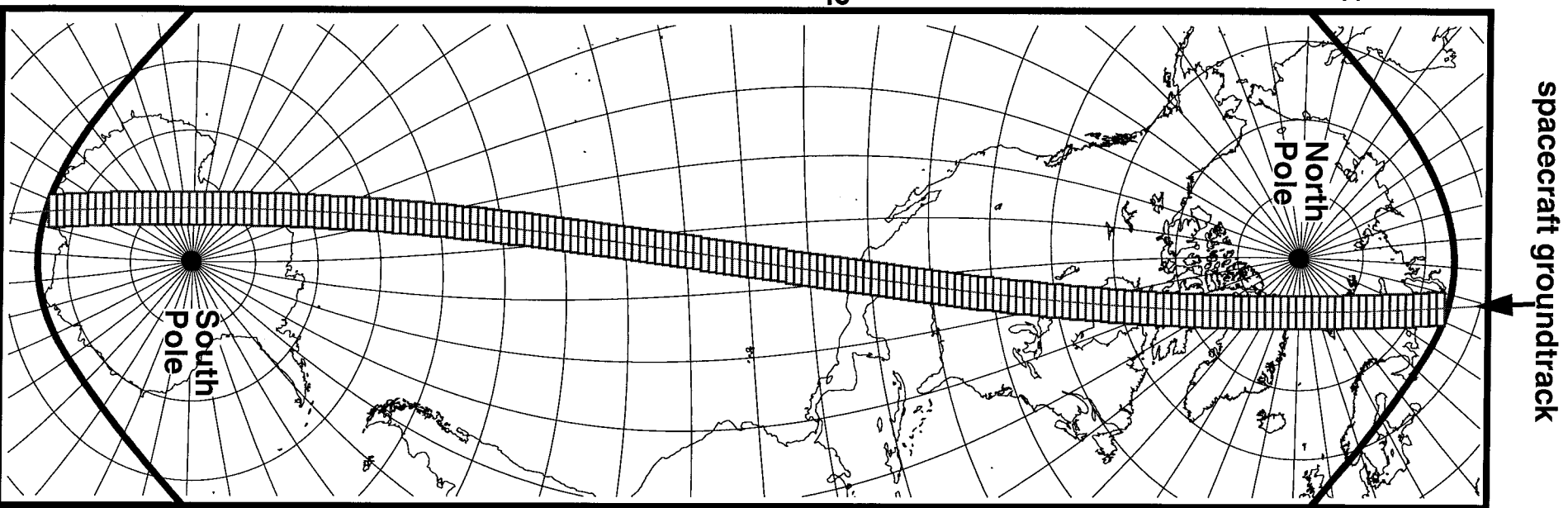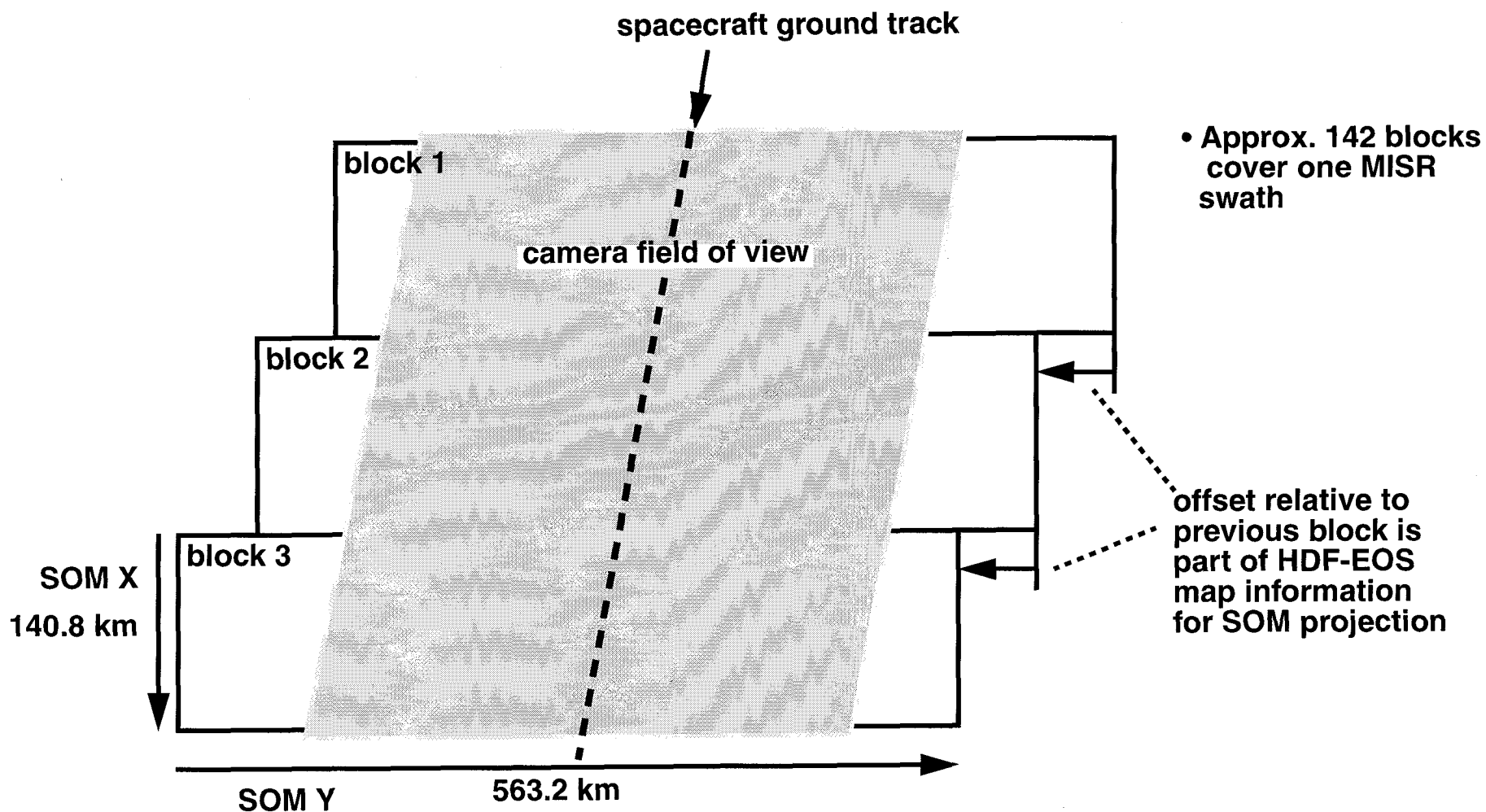   - Resolution is 1 degree by 1 degree.

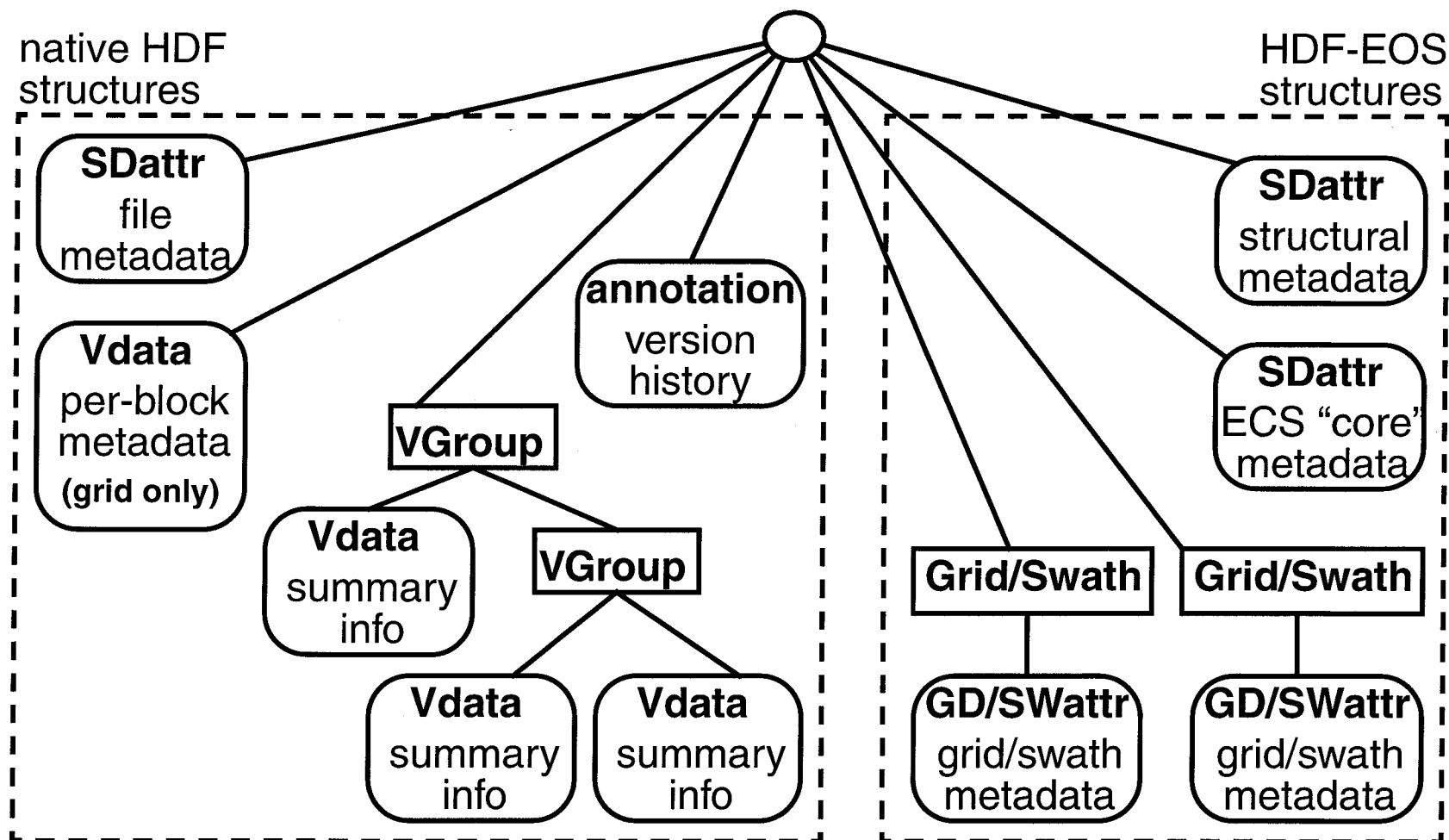North
Day / Night
Terminator
(Summer
Solstice)

- 180 blocks
from North
Terminator
To South
Terminator

- Approx. 142
blocks in
daylight at
any given
time.

spacecraft groundtrack

South
Pole

North
Pole

South
Day / Night
Terminator
(Winter
Solstice)

+X

SOM axes

+Y

SOM
Path 27

SOM Map Projection & SOM Blocks

JPL

MISR

spacecraft ground track

block 1

camera field of view

- Approx. 142 blocks cover one MISR swath

block 2

block 3

SOM X
140.8 km

offset relative to previous block is part of HDF-EOS map information for SOM projection

SOM Y   563.2 km

Metadata heirarchy of a MISR product file

native HDF
structures

HDF-EOS
structures

SDattr
file
metadata

Vdata
per-block
metadata
(grid only)

annotation
version
history

VGroup

Vdata
summary
info

VGroup

Vdata
summary
info

Vdata
summary
info

SDattr
structural
metadata

SDattr
ECS "core"
metadata

Grid/Swath

Grid/Swath

GD/SWattr
grid/swath
metadata

GD/SWattr
grid/swath
metadata

- **File metadata**
  - Attributes associated with an entire file -- not specific to a grid or swath. (e.g. orbit path number)
  - Stored using HDF Scientific Dataset (SD) attributes.

gid = GDopen(filename)
EHidinfo(gid,&hdf_id,&sid)
SDsetattr(sid, attribute_name,...)
GDclose(gid)

- **Per-block metadata**
  - Metadata associated with each SOM block in an SOM projected grid. (e.g., "ocean flag", indicating if block is over ocean)
  - Stored using an HDF Vdata, with one record for each block.

Vdata

record#	block number	ocean flag	block corners	data valid
0	1	true	(upper left,	true
1	2	true	lower right	true
2	3	false	corner)	true
:	:	:	:	:

gid = GDopen(filename)
EHidinfo(gid,&hdf_id,&sid)
Vstart(hdf_id)
vdata_id = VSattach(hdf_id,...)
VSwrite(vdata_id,...)
VSdetach(vdata_id)
GDclose(gid)

- **Version History**
  - Records information describing how the file was created.
  - Stored using HDF Single-file Annotations (DFAN) - file descriptions.

  hdf_id = Hopen(filename, ...)
  DFANaddfds(hdf_id, description_1,...)
  DFANaddfds(hdf_id, description_2,...)
  Hclose(hdf_id)

  3 File Descriptions:
  1. Runtime information -- operating system, environment variables, date of run
  2. Input files -- full pathname of each input file
  3. Executable information -- software version, libraries, compiler flags, date of build

- **Summary Information (Quality Assessment)**
  - Summary of data. (e.g., number of pixels with "bad" data quality)
  - Stored using VGroups and Vdatas.

  hdf_id = Hopen(filename,...)
  Vstart(hdf_id)
  vgroup_id = Vattach(hdf_id,...)
  vdata_id = VSattach(hdf_id,...)
  VSwrite(vdata_id,...)
  VSdetach(vdata_id)
  Vdetach(vgroup_id)
  Hclose(hdf_id)

- **Definition of "Upper Left"**
  - MISR defines the "upper left" corner of an SOM block to be the corner with the <u>minimum</u> SOM X, and <u>minimum</u> SOM Y coordinate.
  - HDF-EOS defines the "upper left" corner of the SOM grid to be the corner with the <u>minimum</u> SOM X and <u>maximum</u> SOM Y coordinate.

MISR "upper left"   HDF-EOS "upper left"

SOM X

SOM block

SOM Y
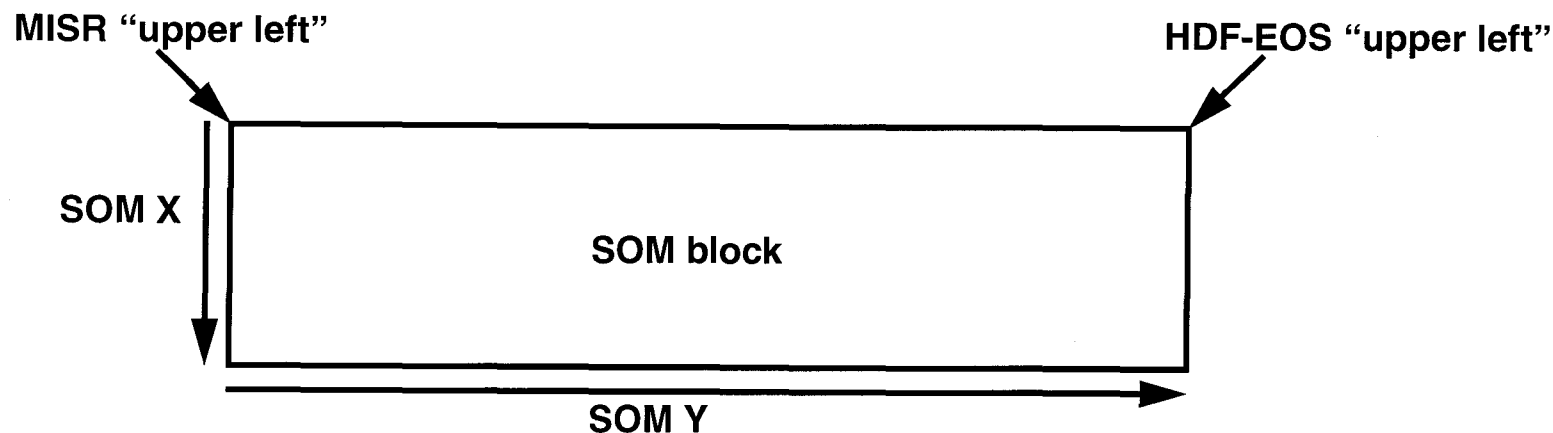
- In a geographic projection (lat / lon coordinates), an SOM block rotates through 180 degrees at the North and South pole. As a result, the MISR "upper left" corner can be northwest, northeast or southeast, depending on location. (see diagram on page 4)

- **Compression & Tiling**
  - Compression requires tiling, unless one data write operation is performed.
  - For SOM projected MISR data, one tile corresponds to one SOM block -- because most of our processing works with units of SOM blocks.
  - MISR cannot use compression for swath datasets due to lack of tiling capability in HDF-EOS swath -- our data is too large to write in one operation.

- **Data Scaling**
  - Storing 32-bit float as 16-bit integer or 8-bit integer.
  - Scale factor depends on dynamic range of floating point data and range of integer values available for scaled data.
  - Usually need to reserve one or more integer values to encode special flags (e.g. "underflow", "overflow", "no data")

  Example: dynamic range [0.0 - 5.0] scaled to 16-bit with 3 reserved flags values
      0 to 65532: scaled data
          65533: no data (fillvalue)
          65534: overflow flag
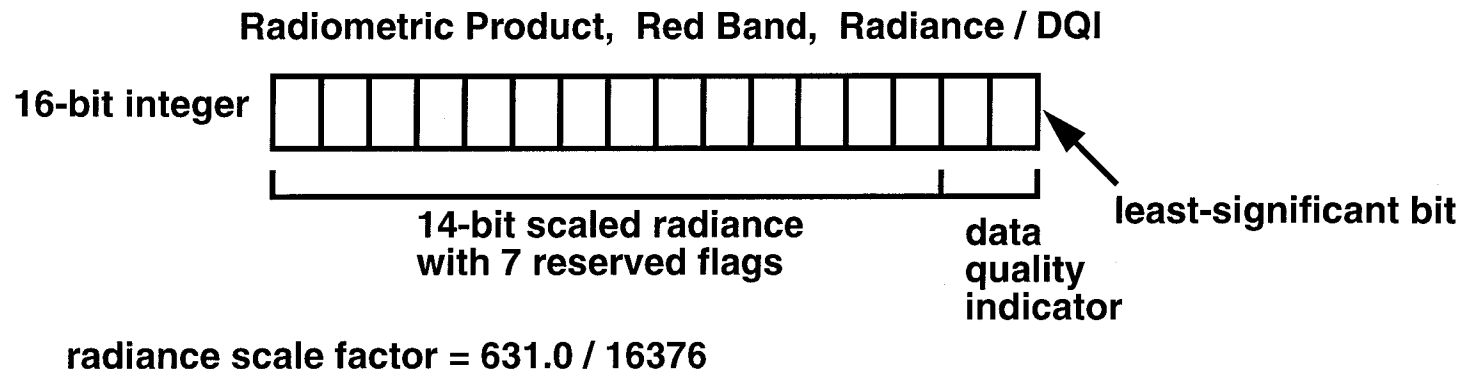   65535: underflow flag
      scale factor = 5.0 / 65532

- **Data Packing**
  - Storing more than one logical field into one physical field. (e.g., pack 2-bit data quality flag and 14-bit image data into a 16-bit integer)
  - Use of least significant and most significant bits is important to consider.
  - Can use negative sign of float value as a flag (e.g. "interpolated" flag) -- but may be trouble for data visualization tools, and confusing to the end user.
  - Packing and scaling can be combined.

  Example: 14-bit scaled radiances, with dynamic range [0.0 - 631.0], and 7 reserved flag values (16377 to 16383), packed into a 16 bit integer along with a 2-bit data quality indicator.

Radiometric Product, Red Band, Radiance / DQI

16-bit integer

14-bit scaled radiance with 7 reserved flags **data quality indicator** **least-significant bit**

radiance scale factor = 631.0 / 16376

- **HDF-EOS error checking is not always implemented**
  - HDF-EOS calls may return a success status even though internal native HDF calls failed.
  - Can make file corruption problems difficult to track down.
  - Allows failures to slip through undetected by higher level routines.

- **Using Fill Values with Tiling**
  - You may <u>not</u> set a fill value for a given field after tiling has been defined for that field. The fill value must be set first!
  - Requires a call to GDsettilecomp() function <u>after</u> GDsetfillvalue().

Case 1 (silently fails)

```
GDdeftile(grid_id,...)
GDdeffield(grid_id,fieldname,...)
GDsetfillvalue(grid_id,fieldname,...)
```

GDsetfillvalue returns a success status, but the fill value is not set!

Case 2 (succeeds)

```
GDdeffield(grid_id, fieldname,...)
GDsetfillvalue(grid_id,fieldname,...)
GDsettilecomp(grid_id,fieldname,...)
```

Fill value is set.

[1] Scott Lewicki, et. al., "Data Product Specifications," JPL D-13963, Revision C